

Effect of pressure on magnetic structure in heavy fermion CeRhIn_5

W. Bao¹, S.F. Trevino^{2,3}, J.W. Lynn², P.G. Pagliuso¹, J.L. Sarrao¹, J.D. Thompson¹, Z. Fisk^{1,4}

¹ Los Alamos National Laboratory, Los Alamos, NM 87544, USA

² Center for Neutron Research, National Institute of Standards and Technology, Gaithersburg, MD 20899, USA

³ United States Army Research Laboratory, Adelphi, MD 20783, USA

⁴ Florida State University, Tallahassee, FL 32306, USA

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Abstract The effect of hydrostatic pressure on the incommensurate antiferromagnetic structure of CeRhIn_5 is investigated with neutron diffraction using a He pressure cell. At 3.8 kbar, the staggered magnetic moment is $0.37(4) \mu_B$ per Ce at 1.6 K, which is the same as the ambient-pressure value. The Néel temperature $T_N = 3.8(1)$ K is also the same as the ambient-pressure one, although the curve of order parameter has changed by pressure. The incommensurability δ of the magnetic wave vector $\mathbf{q}_M = (1/2, 1/2, \delta)$ has reduced from $\delta = 0.297$ at ambient pressure to $\delta = 0.294(1)$ at 3.8 kbar.

1 Introduction

Superconductivity and antiferromagnetism exist in close proximity in the heavy fermion materials with chemical formula CeMIn_5 , which have Sommerfeld constants $\gamma = 0.4, 0.7$, and 0.3 J/mole K^2 for $M = \text{Rh}, \text{Ir}$, and Co , respectively[1,2]. These tetragonal materials (HoCoGa_5 structure with space group No. 123, $P4/\text{mmm}$) consist of alternating layers of the cubic heavy fermion antiferromagnet CeIn_3 and intervening MIn_2 [3]. At ambient pressure, CeRhIn_5 is an antiferromagnet below $T_N = 3.8$ K, with magnetic moments on the Ce ions, $0.374(5) \mu_B$ at 1.4 K, lying in the basal plane and forming an incommensurate transverse spiral with a magnetic wave vector $\mathbf{q}_M = (1/2, 1/2, 0.297)$ [4,5]. Under a pressure of 17 kbar, CeRhIn_5 becomes a superconductor below $T_C = 2.1$ K[1]. Both CeIrIn_5 and CeCoIn_5 are superconductors at ambient pressure with $T_C = 0.4$ and 2.3 K, respectively[2]. Lines of nodes in the superconducting gap have been indicated from thermodynamic, transport, and NQR measurements[6,7,8,9]. This type of anisotropic superconductivity in heavy fermion materials is widely believed to be mediated by antiferromagnetic fluctuations.

While a two-dimensional (2D) Fermi surface of undulating cylinders is detected in de Haas-van Alphen measurements[10], anisotropic 3D antiferromagnetic correlations are observed in direct measurements using neutron scattering[11] and inferred from a theoretical fit to NQR measurements[7,8].

Anisotropic magnetic correlation lengths of CeRhIn_5 indicate that the antiferromagnetic nearest-neighbor interaction in the CeIn_3 layer is stronger than the magnetic interaction between Ce neighbors that are separated by the RhIn_2 layer[11]. This may play a role in stabilizing the commensurate antiferromagnetic structure of Ce_2RhIn_8 [12], which can be viewed as a periodic stacking of 2 layers of CeIn_3 on a layer of RhIn_2 . The incommensurate magnetic structure of CeRhIn_5 is robust. While T_N is reduced linearly to zero with La doping on the Ce site at a critical dopant concentration around 0.4[13], the magnetic structure of $\text{Ce}_{0.9}\text{La}_{0.1}\text{RhIn}_5$ ($T_N = 2.7$ K) is still characterized by $\mathbf{q}_M = (1/2, 1/2, 0.297)$ and a staggered moment of $0.36(2) \mu_B$ at 1.4 K[14]. Applying pressure to CeRhIn_5 or doping it with Ir on the Rh site has only a small effect on T_N until the material becomes a superconductor[1,8,15]. We have found with neutron diffraction measurements that the suppression of the antiferromagnetic phase by Ir doping is through progressive reduction of the staggered moment of the incommensurate magnetic spiral[16]. Here we report the effect of pressure on magnetic structure of CeRhIn_5 .

2 Experiments and Results

High pressure neutron diffraction experiments were performed at NIST using the thermal triple-axis spectrometer BT2 in a two-axis mode. To reduce neutron absorption by In and Rh, neutrons of incident energy $E = 35$ meV were selected using the (002) reflection of a pyrolytic graphite (PG) monochromator. A PG filter of 5 cm thickness was inserted in the incident neutron beam to remove higher order neutrons. The horizontal collimations were 60-40-40.

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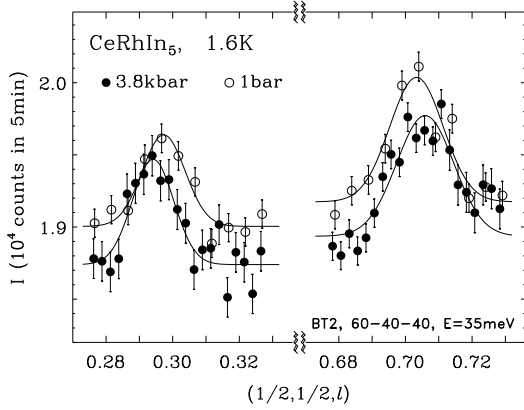


Fig. 1 Elastic scan through a pair of magnetic Bragg points at 1.6 K and under pressure of 3.8 kbar (solid circles) and 1 bar (open circles).

The pressure cell[17] was made of a BeCu alloy, Berylo 25. The cell body is a cylinder with outer diameter 1/2 inch and inner diameter 1/8 inch. Helium was used as the pressure transmitting medium and was compressed into the pressure cell through a stainless steel capillary. The pressure in the cell was monitored by a manganin resistance gauge and by measuring the lattice constant of graphite in the cell. During the experiment at 3.8 kbar, pressure decreased 0.04 kbar due to small He leaks.

The single crystal sample of CeRhIn_5 was grown from an In flux. It was cut to a rectangular bar to fit inside the pressure cell so that the axis of the cell was parallel to the $(1, -1, 0)$ crystal orientation. The neutron scattering plane was the (hhl) plane. The pressure cell was mounted on the cold finger of a top loading, pumped He cryostat.

Solid circles in Fig. 1 show a pair of magnetic Bragg peaks in a Brillouin zone, measured at 3.8 kbar. No other peaks were found along the $(1/2, 1/2, l)$ line in a search from $(1/2, 1/2, 0)$ to $(1/2, 1/2, 1)$. Compared to data measured at 1 bar (see open circles), it is clear that the period of the incommensurate spiral increases with pressure. The magnetic wave vector, $(1/2, 1/2, \delta)$, changes from $\delta = 0.297(1)$ [4] at ambient pressure to $0.294(1)$ at 3.8 kbar. Intensities of the magnetic Bragg peaks at the two pressures, however, remain the same within the error bars. The staggered moment is determined to be $0.37(4) \mu_B$ per Ce ion by comparing magnetic Bragg intensities of the 3.8 kbar and 1 bar measurements.

The intensity of the $(1/2, 1/2, 0.706)$ magnetic Bragg peak is shown in Fig. 2 as the square of the order parameter of the magnetic phase transition at 3.8 kbar. The Néel temperature changes little, which is consistent with bulk and NQR measurements[1,8]. However, the intensity increases more rapidly below T_N under pressure as compared to the ambient pressure result.

Mito and co-workers recently reported a linear reduction with pressure of the internal field at the In(1) site

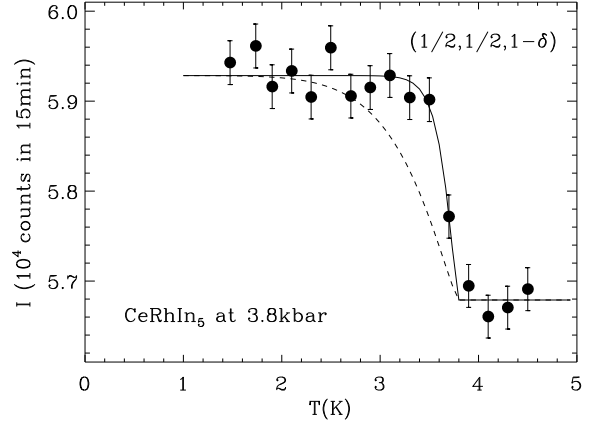


Fig. 2 Temperature dependence of the $(1/2, 1/2, 0.706)$ magnetic Bragg peak of CeRhIn_5 under 3.8 kbar pressure. The solid line is a guide to the eyes, and the dashed line represents the square of the order-parameter curve at 1 bar[4].

in an NQR study on CeRhIn_5 [8]. They suggested that either the staggered moment decreased with pressure or the moment tilted progressively towards the c -axis when pressure was raised to the critical pressure of 16.3 kbar. The former explanation would imply a $\sim 25\%$ reduction of the staggered moment at 3.8 kbar and is not consistent with our data. The latter explanation may lead to extra magnetic Bragg peaks characterized by a wave vector $(1/2, 1/2, 0)$ or $(1/2, 1/2, 1/2)$, which we do not observe in our work. One possibility is that the hyperfine interaction at the In(1) site may be sensitive to pressure.

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References

1. H. Hegger, C. Petrovic, E.G. Moshopoulou, et al., Phys. Rev. Lett. **84**, 4986 (2000).
2. C. Petrovic, R. Movshovich, M. Jaime, et al., Europhys. Lett. **53**, 354 (2001); C. Petrovic, P. G. Pagliuso, M.F. Hundley, et al., J. Phys. Condens. Mat. **13**, L337 (2001).
3. E.G. Moshopoulou, Z. Fisk, J. L. Sarrao and J. D. Thompson, J. Solid State Chem. **158**, 25 (2001).
4. W. Bao, P. G. Pagliuso, J. L. Sarrao, et al., Phys. Rev. B **62**, R14621 (2000); Erratum: ibid. **63**, 219901(E) (2001).
5. N.J. Curro, P.C. Hammel, P.G. Pagliuso, et al., Phys. Rev. B **62**, R6100 (2000).
6. R. Movshovich, M. Jaime, J.D. Thompson, et al., Phys. Rev. Lett. **86**, 5152 (2001).
7. G.-Q. Zheng, K. Tanabe, T. Mito, et al., Phys. Rev. Lett. **86**, 4664 (2001).
8. T. Mito, S. Kawasaki, G.-Q. Zheng, et al., Phys. Rev. B **63**, 220507(R) (2001).
9. K. Izawa, et al., cond-mat/0104225 (2001).
10. Y. Haga, Y. Inada, H. Harima, et al., Phys. Rev. B **63**, 060503(R) (2001); A.L. Cornelius, A.J. Arko, J.L.

- Sarrao, et al., Phys. Rev. B **62**, 14181 (2000); D. Hall, et al., cond-mat/0011395 (2000); D. Hall, et al., cond-mat/0102533 (2001).
11. W. Bao, G. Aeppli, J. W. Lynn, et al., cond-mat/0102503 (2001).
 12. W. Bao, P. G. Pagliuso, J. L. Sarrao, et al., Phys. Rev. B **64**, 020401(R) (2001).
 13. P.G. Pagliuso, et al., unpublished (2001).
 14. W. Bao, A.D. Christianson, P.G. Pagliuso, et al., cond-mat/0109379 (2001).
 15. P.G. Pagliuso, C. Petrovic, R. Movshovich, et al., cond-mat/0101316 (2001).
 16. A.D. Christianson, W. Bao, et al., unpublished (2001).
 17. W. Bao, C. Broholm and S. F. Trevino, Rev. Sci. Instrum. **66**, 1260 (1995).